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Abstract

Andalusian agricultural sectors are relatively small, but account for 90% of the annual water consumption. More than 50% of the agricultural final demands is exported to other Spanish regions or abroad. Using the concept of virtual water within an input-output framework, we find that a substantial part of the Andalusian water consumption is embodied in its exports. Considering the virtual water content of its trade, Andalusia is a net exporter of water. Examining regional policy aspects, a reduction in the exports abroad of agricultural products yields considerable benefits in terms of water savings while the negative effects are only moderate.

Key words: Input-Output Models, Virtual Water, Trade and Sustainability

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1. Introduction

In arid regions, water shortages not only cause serious physical problems but also hinder the social and economic development of the region (see Aguilera-Klink, 1994). While an appropriate allocation of water may alleviate the pressure on this scarce resource, it appears that a few production sectors account for almost all water consumption. In this paper, we focus on the destination of water in Andalusia – one of the most arid regions in Europe – after it has been embodied in the production of goods and services. Using an input-output framework, we calculate how much water consumption should be attributed to each of the final demands, distinguishing between domestic (i.e. Andalusian), other regional (i.e. Spanish) and foreign destinations. This allows us to determine the trade of water that is directly and indirectly embodied in, for example, the exported products and services.

Our approach implements the concept of virtual water within an input-output framework. Explaining the management of water demand, the concept of virtual water was introduced by Allan (1993, 1994). It is defined as the amount of water that is "contained" in a certain product (Allan, 1998). It should be noted, however, that the term "contained" covers more than just the physical water content of a product and includes all the water that has been consumed in its production process. Input-output analysis is a suitable tool for determining the virtual water content of one euro of product i. It covers the (direct) water consumption in production process i, the water consumption to produce the amount of each good k that is used as an input in process i, the water consumption to produce the inputs necessary for producing this input of k, and so forth. Summing all the requirements gives the amount of virtual water, i.e. the total amount of water embodied in one euro of final demand for product i.

The concept of virtual water is particularly relevant in connection with trade (see e.g. Lenzen and Foran, 2001).[1] For example, a certain region might be able to save water by replacing some of its domestic production of water intensive goods by imports from regions that are relatively water abundant. This immediately relates to the Heckscher-Ohlin theory (Wichelns, 2001; Hakimian, 2003; Sayan, 2003), which states that relatively water abundant regions export goods and services that are produced in a relatively water intensive way. Many of the semi-arid countries in the Middle East have approached their water problems in this way and introduced appropriate food policies and strategies. For instance, Israel and Jordan have reduced (or even abandoned) the export and the production of water intensive crops, so as to optimize the allocation of the scarce water resources (see van Hofwegen, 2003). The virtual water content of imports and exports also plays an important role in determining the so-called water footprints (see e.g. Chapagain and Hoekstra, 2004).[2] The water footprint of a nation, for example, gives the total volume of water used in the production of goods and services consumed by the inhabitants of that country. Trade matters, because inhabitants consume imported products and thus foreign virtual water, while at the same time domestic water is used in the production of export products that are consumed abroad.

The plan of the paper is as follows. Section 2 briefly discusses some of the geographical and economic characteristics of Andalusia that are relevant for our study. The input-output framework in relation to water consumption is presented in Section 3. As descriptive measures, we will discuss the direct water coefficients and the virtual water multipliers. Section 4 appropriates water consumption to the actual final demands to determine the virtual water contents. The sensitivity of product prices to water pricing and its relation to regional policy aspects are taken into account in Section 5. We discuss how nullifying certain exports affects total water consumption, gross regional product, employment, and the regional trade balance. Section 6 deals with the virtual water content of Andalusian imports and exports, and examines whether its trade pattern is in line with the Heckscher-Ohlin theory. Our conclusions are given in Section 7.

2. Geographical and development aspects

Apart from being a vital element for life, water is also a strategic resource for any economic activity. The extent to which water is available may condition the development of a region in a significant way. In order to determine the role that water plays in the Andalusian economy, we will discuss some geographical features of the region as well as some relevant aspects about water in Andalusia and its main uses.

Andalusia is strategically located in the south of Spain and may be described as a vast triangular plain of 87,561 Km^2 (which is 17% of the Spanish territory). This plain is bordered in the north by the Sierra Morena and the Bética mountains; in the south-west by the Atlantic Ocean; and in the east and south-east by the Mediterranean Sea. Due to this geographical situation, Andalusia has a Mediterranean climate, characterized by irregular rainfall – both over time and across space – and long hot summers with high evapotranspiration.

The hydrographical network consists of five river basins: the Guadalquivir basin, the Guadiana basin and the Guadalete-Barbate basin, each flowing into the Atlantic Ocean; and the South basin and the Segura basin flowing into the Mediterranean Sea. The data in Table 1 show the sizes of the basins and the amounts of water they provide (note that the Guadiana basin is split into two parts). The figures in the first column give the total size of each basin (in Km^2). Some basins (in particular Guadiana I and Segura), however, are essentially outside Andalusia. The figures in the second column give the size of each basin within Andalusia, and those in the third column the percentage of the total Andalusian territory that they cover. With 59%, the Guadalquivir basin is clearly the largest within Andalusia. The figures in the fourth and fifth column show how much water (in billion liters per year) is provided by each of the basins. Note that 73% of this is surface water, while 27% is from underground reservoirs.

INSERT TABLE 1

The economic development of Andalusia has induced an increase in the demand for water over time. In its turn, this has led to a stronger pressure on the scarce water resources. As we will see in more detail in the next section, the agricultural sectors absorb 90% of the available water resources due to the very large amount of irrigated land. According to Lopez-Fuster and Montoro (2002, p. 3), Spain ranks third in the world and first in Europe, in terms of irrigated land. Andalusia covers 23.3% of the Spanish irrigated land (Consejería de Agricultura y Pesca, 1999, p. 84). This is a very high percentage if we take into account that Andalusia is the most arid region in the country and the one with the most serious problems of water shortages. The problems are further aggravated because the existing irrigation systems are rather old and only few hi-tech systems that save water are used. Irrigation by gravity is still the system that is used most widely in the region (44.9%).

In addition, the effects of the large number of tourists that visit the Andalusian coast should be mentioned. Tourism has become one of the important drivers of the region. Especially in the summer, tourist activities require a lot of water, which conflicts with the use in the agricultural sector. Agricultural activities and tourism together have risen the demand for water to such an extent that the coastal areas are mostly irrigated with underground water. A consequence of this is that intrusion of salty sea water takes place, which raises the problems due to overexploitation even further. Also the manufacturing sector has undergone a large expansion over time. This occurred mainly in the Guadalquivir river basin and around the major cities and the main harbours of the region. The expansion involved in particular food processing and the agricultural products sector, both of which consume considerable amounts of water (Velázquez, 2005).

3. An explorative analysis of water consumption

In this section we will discuss water consumption at the sectoral level. We have used the Andalusian input-output table for 1990 (see Instituto de Estadística de Andalucía, 1995) and data on water consumption (Agencia de Medio Ambiente, 1996). The first column in Table 2 gives the vector **w** with sectoral water consumption (in billion liters). It shows that 90% of all the water consumption takes place in the agricultural cluster (sectors 1-6). The manufacturing cluster (sectors 7-19) and the services cluster (sectors 20-25) account each for 5% of the water consumption. The second column gives the vector **x** with sectoral production (in million euros). It follows that agriculture accounts for only 8% of the total output value, manufacturing for 34%, and services for 58%. So, almost all water is consumed by sectors that are responsible only for a minor share in the output value. This suggests that the prices for the agricultural prices are too low, once water is priced according to its scarcity.

INSERT TABLE 2

The third column in Table 2 gives the vector **y** with direct water input coefficients. They are defined as $y_i = w_i / x_i$ and describe the water consumption (in liters) per euro of production. On average this coefficient is 53, but note that there is an extreme variance across sectors. In particular citrus fruits (sector 3) and cereals and legumes (sector 1) require an enormous amount of water per euro of output. Also the other four agricultural sectors are well above average. Consequently, the manufacturing and service sectors must have coefficients much smaller than average. We see that only three manufacturing sectors (metallurgy, 9; chemicals and plastics, 11; and paper, printing and publishing, 18) and one service sector (hotel and catering, 22) consume more than 5 liter per euro production.

Although cereals and legumes (sector 1) has a very high direct water input coefficient and absorbs more than 25% of all the water, a large part of its products are sold to the food processing sector (14). So, indirectly, the food products contain a considerable amount of water, because this sector requires cereals and legumes as its inputs. The appropriate way to take all such indirect effects into account is by using an input-output framework. Consider the input-output table (in monetary terms) as given by Table 3.

INSERT TABLE 3

The typical element z_{ij} of the $n \times n$ matrix **Z** gives the intraregional intermediate deliveries. That is, the deliveries from sector *i* in Andalusia to sector *j* in Andalusia, with *i*, *j* = 1, …, *n*. The element f_{ij} of the $n \times k$ matrix **F**, gives the deliveries of sector *i* in Andalusia to the final demand category *j* (= 1, …, *k*). The final demand categories are private consumption, public consumption, investments, exports to the rest of Spain, exports to other EU countries, and exports to the rest of the world. The row vector $\mathbf{v}'$ gives the value added in each sector (which comprises wages and salaries, depreciation, operating surplus, and indirect taxes minus subsidies). Note that the sum of this vector gives the total value added in Andalusia, which is its gross regional product (GRP, similar to GDP). The typical element m_{ij} of the $n \times n$ matrix **M** gives the imports that originate in a "foreign" (i.e. either in the rest of Spain or in an other country) sector *i* and that are bought by the Andalusian sector *j*. The elements x_i of vector **x** give the (gross) output or money value of the production in sector *i* in Andalusia.

Note that the sectoral outputs may be obtained by summing over the rows or the columns. Summing over the columns yields the following accounting equation; $x_i = \Sigma_j z_{ij} + \Sigma_j f_{ij}$. Direct input coefficients are defined as $a_{ij} = z_{ij} / x_j$ and they indicate the (extra) input in euros from sector *i* in Andalusia, that is required for the (extra) production of one euro by sector *j* in Andalusia. Using this definition and collecting the final demand categories (i.e. $f_i = \Sigma_j f_{ij}$), implies that the accounting equation can be rewritten as $x_i = \Sigma_j a_{ij} x_j + f_i$, or as $\mathbf{x} = \mathbf{Ax} + \mathbf{f}$ in matrix notation.

If the matrix **A** with direct input coefficients is assumed to be constant, it is possible to evaluate how much output each sector must produce for any given (i.e.

exogenously specified) final demand vector (say $\tilde{\mathbf{f}}$). The solution yields $(\mathbf{I}-\mathbf{A})^{-1}\tilde{\mathbf{f}} = \mathbf{L}\tilde{\mathbf{f}}$, where $\mathbf{L} = (\mathbf{I}-\mathbf{A})^{-1}$ denotes the Leontief inverse or multiplier matrix. Taking $\tilde{\mathbf{f}} = (0,...,0,1,0,...,0)'$, i.e. the *j*th unit vector, provides the interpretation of the elements of the Leontief inverse. That is, l_{ij} gives the (extra) output in sector *i* that is necessary for one (extra) euro of final demand in sector *j*. These elements of **L** take all direct and indirect effects into consideration. Taking the column sums of the Leontief inverse gives the so-called output multipliers. That is, $\Sigma_i l_{ij}$ indicates the total (extra) output that must be produced for one (extra) euro of final demand in sector *j*.

Multiplying the elements l_{ij} by the direct water input coefficient y_i (i.e. $y_i l_{ij}$) tells us how many (extra) liters of water are (directly and indirectly) consumed by sector i for generating one (extra) euro of final demand in sector *j*. Summing over *i* gives the total (extra) amount of virtual water that is required per (extra) euro of final demand in sector *j*. These virtual water multipliers (i.e. $\Sigma_i y_i l_{ij}$) are given in the fourth column of Table 2.

Note that the average virtual water multiplier (= 74) is 38% larger than the average direct water input coefficient (= 53). The first is obtained as the total water consumption (3,365 billion liters) divided by the total final demands (45,651 million euros).[3] It thus gives the weighted average of the separate water multipliers, using sectoral final demands as weights. The average direct water input coefficient is obtained by dividing the total water consumption by total production (62,952 million euros). The average direct water input coefficient uses sectoral outputs as weights.

The results in Table 2 for the water multipliers again show the distinction between the agricultural sectors (1-6) and the other sectors. Two of these sectors that should be mentioned are food processing (sector 14) and hotel and catering trade (22).

Both have considerable multipliers but only modest direct water input coefficients. This means that relatively little water is consumed by the sectors themselves, but indirectly a fairly large amount of water is necessary for their products. The matrix **A** of intermediate input coefficients confirms that hotel and catering trade strongly relies on inputs from food processing, which in its turn relies heavily on inputs from the agricultural sectors that are highly water intensive.

4. The virtual water content of final demands

The Andalusian input-output table lists several final demand categories. For our analyses, we have aggregated them into the following four. Domestic (i.e. Andalusian) final demand (indicated by the vector $\mathbf{f}^{AND}$), which covers private and public consumption and investments; exports to the rest of Spain ($\mathbf{f}^{RoS}$); exports to the rest of the European Union ($\mathbf{f}^{RoEU}$); and exports to the rest of the world ($\mathbf{f}^{RoW}$). These final demand vectors are listed in the first four columns of Table A1 in the Appendix. They show that more than 50% of the final demands in agriculture (sectors 1-6) is exported. Given the extremely large virtual water multipliers, it may be expected that Andalusia indirectly exports a substantial amount of virtual water.

To analyze the total (i.e. direct and indirect) water consumption that is necessary for the actual final demands (in million euros) we have calculated $\Sigma_{i=1}^{25} y_i l_{ij} f_j^{AND}$ for $j = 1, \ldots, 25$. This gives the water consumption (in billion liters) that can be appropriated to the actual Andalusian final demand for product j, i.e. its virtual water content. For the other categories we have $\Sigma_{i=1}^{25} y_i l_{ij} f_j^{RoS}$, $\Sigma_{i=1}^{25} y_i l_{ij} f_j^{RoEU}$, and

$\Sigma_{i=1}^{25} y_i l_{ij} f_j^{RoW}$, respectively. The results are given in the columns (5)-(8) in Table A1. For example, the 34.6 million euros of Andalusian final demand for cereals and legumes have required, directly and indirectly, 66.3 billion liters of total water.

A summary of the detailed results in Table A1, is given in Table 4. The sectors have been aggregated into the clusters Agriculture (sectors 1-6), Manufacturing (7-19) and Services (20-25). The results give the final demands as a percentage of the total final demands (45,650.8 million euros) and their virtual water contents as a percentage of the total water consumption (3,364.7 billion liters). It turns out that the final demands for agricultural products are only 6% of the total final demands but their production requires no less than 54% of all water consumption. Final demands for services, on the other hand, amount to 61% of the total and are responsible for only 13% of the total water consumption. Note that exports to other regions or countries are 27% of all final demands, but account for more than half (52%) of the total water consumption.

INSERT TABLE 4

The most striking result is that the exports of agricultural products are only 3% of the total final demands, but their virtual water content is 30% of the total water consumption. Another major water using sector is food processing. From Table A1 it follows that its final demands are 11% (its exports 7%) of the total final demands, while the virtual water content is 29% (respectively 19%) of the total water consumption.

5. Price sensitivity and policy aspects

In this section, we will first show how the virtual water multipliers in Table 2 can be interpreted as changes in the prices of the products, resulting from a cost-push. Assume that the price of water is set at (or increased by) 1 euro per m^3 (= 1000 liters). In Section 3, we have obtained the accounting equation $x_i = \Sigma_j z_{ij} + \Sigma_j f_{ij}$ from the rows in Table 3, which led to the quantity model **x** = **Ax** + **f**. Using the columns in the input-output table leads to the accounting equation $x_j = \Sigma_i z_{ij} + \Sigma_i m_{ij} + v_j$. A common assumption (which, however, is rarely mentioned explicitly) is that the current price of each product is 1 euro. This implies that the physical unit of measurement is chosen appropriately, namely as the amount (e.g. in kilograms or meters) that can be bought for 1 euro. Dividing the accounting equation by x_j gives $1 = \Sigma_i (z_{ij} / x_j) + \Sigma_i (m_{ij} / x_j) + (v_j / x_j) = \Sigma_i a_{ij} + \Sigma_i (m_{ij} / x_j) + (v_j / x_j)$. This equation states that the price (i.e. 1 euro) of one physical unit of product *j*, equals the costs involved in producing that unit. These costs consist of domestic inputs ($\Sigma_i a_{ij}$), imports ($\Sigma_i m_{ij} / x_j$) and value added items (v_j / x_j, including wages and salaries and the operating surplus). In matrix notation, the set of equations yields $\mathbf{e}' = \mathbf{e}'\mathbf{A} + \mathbf{e}'\mathbf{M}\hat{\mathbf{x}}^{-1} + \mathbf{v}'\hat{\mathbf{x}}^{-1}$, where **e** denotes the summation vector consisting of ones.[4] Rewriting yields $\mathbf{e}' = (\mathbf{e}'\mathbf{M}\hat{\mathbf{x}}^{-1} + \mathbf{v}'\hat{\mathbf{x}}^{-1})(\mathbf{I} - \mathbf{A})^{-1} = (\mathbf{e}'\mathbf{M}\hat{\mathbf{x}}^{-1} + \mathbf{v}'\hat{\mathbf{x}}^{-1})\mathbf{L}$.

Suppose that we now introduce the costs of using water and let $\tilde{w}_j$ denote the water costs (in euros) in sector *j*. The price of product *j* will therefore change, because it also has to cover the costs of using water. Let p_j denote the new price of one physical unit of product *j*. Equating the new price to the total costs per physical unit yields $p_j = \Sigma_i p_i a_{ij} + \Sigma_i (m_{ij} / x_j) + (v_j / x_j) + (\tilde{w}_j / x_j)$. Note that the domestic inputs are sold at new prices p_i. In matrix notation, we have $\mathbf{p}' = (\mathbf{e}'\mathbf{M}\hat{\mathbf{x}}^{-1} + \mathbf{v}'\hat{\mathbf{x}}^{-1} + \tilde{\mathbf{w}}'\hat{\mathbf{x}}^{-1})\mathbf{L}$. Subtracting the new price equation from the equation for the current prices yields $\mathbf{p}' - \mathbf{e}' = \tilde{\mathbf{w}}'\hat{\mathbf{x}}^{-1}\mathbf{L}$. That is, the price change for product *j* equals $p_j - 1 = \Sigma_i (\tilde{w}_i / x_i) l_{ij}$. Recalling that the current price is set at 1, an outcome of $p_j = 1.04$ for example would indicate that the new price of product *j* is 4% higher than the current price.

Let us now return to Table 2 and consider sector 1 (cereal and legumes), which has an output value x_1 of 482 million euros and which uses 883 billion liters of water. Introducing a water price of 1 euro per 1000 liters (or increasing the current water price by that amount) implies that the water costs $\tilde{w}_1$ in this sector yield (or increase by) 883 million euros. Note that $\tilde{w}_i = 0.001 \times w_i$, with w_i the water use in Table 2. The price increases (i.e. $\Sigma_i (\tilde{w}_i / x_i) l_{ij}$) are thus readily obtained from dividing the virtual water multipliers (i.e. $\Sigma_i y_i l_{ij}$ with $y_i = w_i / x_i$) in the last column of Table 2 by 1000. For sector 1, for example, this implies that the current price of the product in this sector is increased by 192.7% if the price of water is increased by 1 euro per 1000 liters. It should be emphasized that the results for another initial price increase for water can easily be derived. For instance, if the price of water is raised by 0.3 euro per 1000 liters, the price in sector 1 would increase by 0.3×192.7 = 57.8%. The same methodology can also be applied straightforwardly if the increase in the price of water differs per sector.

The results in Table 2 show that introducing a water price of 1 euro per 1000 liters (or increasing the current water price by that amount) leads to huge increases in the prices of the agricultural products. They range from 25.8% for other agricultural products (sector 6) to 313.6% for citrus fruits (sector 3). The prices for products from the manufacturing and services sectors all increase by less than 10%, except for the price of food processing products (sector 14) which is raised by 19.0%.

The sensitivity of product prices to a cost push implies that water pricing might be used as a policy option.[5] Introducing water prices (or increasing them) may generate two effects. First, in sectors that use water directly this will decrease the spoiling of water and will stimulate to use water more efficiently. In its turn, this will lead to a decrease in the direct water coefficients $y_j = w_j / x_j$. Second, increased prices of the products (e.g. due to water pricing) will cause a decrease in demand and consequently a decrease in the use of water. A full quantification of this effect would require demand elasticities or a CGE model and a detailed description of a policy device for water pricing. This would include information on how the receipts of water pricing are spent (e.g. redistributed through subsidies). Such an exercise, however, is beyond the scope of this paper and in the remainder of this section we will limit ourselves to sketching the beneficial effects on water saving in relation to other effects.

The results in the previous section show that 49% of the actual water consumption could have been saved, if Andalusia had stopped exporting agricultural products and food processing goods (which, together, account for only 10% of the total final demands). Of course, in considering such a drastic reduction also other effects need to be taken into account. A decrease of the exports implies a fall in production and thus also a drop in employment and value added (or gross regional product, GRP). In addition, the regional trade balance will be affected.

We will calculate the effects of a complete nullification of the "foreign" exports (i.e. to the rest of the EU and to the rest of the world). It is assumed that the exports to other Spanish regions remain as they are. The effects on water consumption can be readily obtained from summing the elements in the columns (7) and (8) of Table A1. To derive the effect on value added, define the direct value added coefficient as $\mu_i = v_i / x_i$, indicating value added per unit of output. A full reduction of the foreign exports of sector *j* reduces the total value added in the region (or gross regional product, GRP) by $\Sigma_{i=1}^{25} \mu_i l_{ij} (f_j^{RoEU} + f_j^{RoW})$. The employment effect could have been obtained in a similar way, if the data had been available. As an approximation, we have computed the reduction in the labor costs. Define $\omega_i = s_i / x_i$, with s_i the wages and salaries (including employers' contributions) paid in sector *i*. Then $\Sigma_{i=1}^{25} \omega_i l_{ij} (f_j^{RoEU} + f_j^{RoW})$ gives the reduction in labor costs due to nullifying the foreign exports of sector *j*. If this reduction is expressed as a percentage of the total labor costs, it equals the percentage reduction in employment if the average wage rate is the same in all sectors. Because this will not be the case, the reduction in labor costs can only be used as an approximation of the employment effect.

If the foreign exports of sector *j* are nullified, the regional trade balance (defined as Andalusian exports minus imports) deteriorates by $f_j^{RoEU} + f_j^{RoW}$. Because the production is reduced as a consequence of the decline in exports, less imports (from the rest of Spain, the rest of the EU and the rest of the world) are required. The decrease in imports amounts to $\Sigma_{i=1}^{25} \eta_i l_{ij} (f_j^{RoEU} + f_j^{RoW})$, with $\eta_i = m_i / x_i$ the direct import coefficients, where m_i denotes the total imports of sector *i*. Hence, the total deterioration of the regional trade balance due to the nullification of the foreign exports of sector *j* yields $(1 - \Sigma_{i=1}^{25} \eta_i l_{ij})(f_j^{RoEU} + f_j^{RoW})$.

A summary of the results is given in Table 5. The first six rows report the effects of the nullification of each agricultural sector separately. The row "Total

Agriculture" shows the effects if the foreign exports are nullified in all agricultural sectors. In the same way, the findings in the row "Total Manufacturing" give the effects of a complete export reduction in all manufacturing sectors (7-19). Given its importance, the results for the food processing sector (14) are also shown separately. The row "Total Services" gives the effects of nullifying the foreign exports in all service sectors (20-25) and the final row "Total" shows the effects for the case in which all foreign exports are abolished.

INSERT TABLE 5

The findings in Table 5 indicate that substantial savings in water consumption may be obtained at relatively low costs (in terms of a reduction in GRP, a decline in employment and a deterioration of the regional trade balance). Consider the nullification of the foreign exports by the agricultural sectors and the food processing sector. Their foreign exports amount to 1,341.1 million euros, which is 3% of the total final demands (and 11% of the total Andalusian exports, including those to the rest of Spain). The water consumption reduces by 16% while the decrease in GRP is only 3%. The 5% fall in labor costs (which may be used as a rough approximation of the reduction in employment) is somewhat higher but still modest. The export reduction implies that also the imports are reduced (by 295.1 million euros) so that the Andalusian trade balance deteriorates by 1,046.0 million euros.

The assumptions that underlie our exercise may seem to be fairly heroic. First, it should be emphasized that we have used a linear model to calculate the effects of a nullification of the foreign exports in a set of sectors. This implies that the results in Table 5 can be used for any other reduction. For example, reducing the foreign exports in vegetables and fruits by 60% and those in food processing by 20% would result in a saving of water by $0.6 \times 6.86 + 0.2 \times 4.99 = 5.11\%$, while the GRP falls by 0.84% and the labor costs by 1.84%. Second, if the effects are triggered by using water pricing as a policy option, it may seem awkward to assume that domestic demand is not affected by the price changes. It should be emphasized that the payments for the virtual water embodied in domestic final demands exactly equal the extra value of these demands due to increased prices. In other words, the government could, in principle, use the receipts from water pricing to ensure that domestic consumers do not have to face price increases. For example, this could be done by leaving the prices unchanged and introducing export tariffs that are equal to the price increases resulting from the last column in Table 2.

6. The virtual water content of trade

The results in the previous sections have shown that the goods produced by the agricultural sectors and by food processing are highly water intensive (accounting for 82.6% of the total amount of water consumption). At the same time, only 38.3% of these products are destined for the domestic Andalusian final demands. We could say that Andalusia exports a major part of its available water, although it is one of the most arid areas in Europe. The question, however, is whether it is a net exporter of virtual water. It might be the case that it imports even more water than it exports.

According to the well known Heckscher-Ohlin (HO) theory of trade, a country exports the products in which it has a comparative advantage. These are the products that intensively use those factors, which are relatively abundant in the country.

Similarly, countries import products that intensively use factors which are relatively scarce in the country. Taking water into account as a production factor, Andalusia has anything but a comparative advantage in producing water intensive goods.[6]

The first empirical test of the HO theory was by Leontief (1953, 1956). He calculated the extra – direct and indirect – labor and capital requirements necessary to satisfy $1 million of extra exports. In the same way, the decreases in requirements were calculated for the case where a reduction of domestic output was replaced by extra imports (to the amount of $1 million). The US was found to export labor intensive goods and to import capital intensive goods, whereas it was commonly believed to be the most capital abundant country at that time. This result has become known as the Leontief paradox and still continues to trigger ample scientific research.

In this section we will calculate the virtual water content of the exports and imports. It is assumed that the exports, for example those to the rest of Spain, are increased by one million euros using the product mix of the current exports. Hence, we construct a vector $\bar{\mathbf{f}}^{RoS}$ that has the same distribution as $\mathbf{f}^{RoS}$, but its elements sum to one million. That is, $\bar{f}_j^{RoS} = 1{,}000{,}000 \times f_j^{RoS} / \Sigma_i f_i^{RoS}$. The water requirements (or virtual water content) of the extra exports of product j are then obtained as $\Sigma_{i=1}^{25} y_i l_{ij} \bar{f}_j^{RoS}$. Leaving the regional trade balance unaffected, it is assumed that also the imports (in this case from the rest of Spain) increase by one million euros. This implies that these products do not need to be produced in Andalusia anymore, so that the regional water requirements decrease. Denote the vector of imports by $\mathbf{m}^{RoS}$, then a one million euro increase of the imports implies that the imports of product j are raised by $\overline{m}_j^{RoS} = 1{,}000{,}000 \times m_j^{RoS} / \Sigma_i m_i^{RoS}$. The water requirements then decrease by $\Sigma_{i=1}^{25} y_i l_{ij} \overline{m}_j^{RoS}$ due to the increased imports of product j.

The total extra water requirements due to the extra exports are given by $\Sigma_{j=1}^{25}\Sigma_{i=1}^{25} y_i l_{ij} \bar{f}_j^{RoS}$ and the total decrease in water requirements due to the extra imports yield $\Sigma_{j=1}^{25}\Sigma_{i=1}^{25} y_i l_{ij} \overline{m}_j^{RoS}$. (In matrix notation the expressions are given by $\mathbf{y}'\mathbf{L}\bar{\mathbf{f}}^{RoS}$ and $\mathbf{y}'\mathbf{L}\overline{\mathbf{m}}^{RoS}$, respectively.) According to the HO theory, a region that is scarce in water would be expected to save water by increasing trade. That is, $\mathbf{y}'\mathbf{L}\overline{\mathbf{m}}^{RoS} > \mathbf{y}'\mathbf{L}\bar{\mathbf{f}}^{RoS}$. In other words, the virtual water content of its imports should be larger than the virtual water content of its exports.

We have calculated the virtual water content for trade with the rest of Spain, with the rest of the EU, with the rest of the world, and total trade. The results are given in Table 6. It should be mentioned that the import vectors we had to use only covered imports by production sectors. For trade with the rest of Spain and for trade with the rest of the EU, Table 6 reports that the virtual water content of Andalusian exports is approximately twice as large as the virtual water content of its imports. For trade with the rest of the world, the exports contain "only" 25% more virtual water than the imports. The results in the total trade case are weighted averages of the separate results, using the actual imports and exports as weights. The imports -in million euros- are 6898 with the rest of Spain; 804 with the rest of the EU; and 2013 with the rest of the world. The corresponding exports are 8930, 1995, and 1466 million euros.

INSERT TABLE 6

In explaining why the exports have a substantially higher virtual water content than the imports have, two aspects stand out. First, the share of agricultural products (which are extremely water intensive) in Andalusian exports is much larger than their share in imports, except for trade with the rest of the world. Second, although the shares of manufacturing in exports and in imports are very similar, it turns out that the share of (relatively water intensive) food processing in exports is a multitude of its share in imports.

7. Conclusions

Andalusia has a considerable water shortage, but at the same time 90% of its water consumption is localized in the agricultural sectors (which generate only 8% of the total production value, 6% of all final demands and 8% of GRP). Therefore, water is a strategic factor in the development of the region. In order to cope with the increasing problems due to the water shortages, an expanded and more effective regulation of water consumption seems necessary. Also a serious reconsideration of the production processes in which the region chooses to specialize in seems appropriate.

Our findings indicated that only 48% of the water consumption should be attributed to regional (i.e. Andalusian) final demands. Hence, no less than 52% of all water consumption appears to be necessary for producing goods and services that are exported to other Spanish regions or other countries. Our calculations have shown that substantial savings in water consumption may be obtained at relatively low costs, in terms of a reduced GRP, a loss of employment and a deterioration of the regional trade balance. For example, stopping the exports to other countries by the agricultural sectors and the food processing sector would reduce water consumption by 16%, while GRP falls only by 3%.

Andalusia is found to be a net exporter of products that intensively use its scarce factor water. Although the agricultural sectors generate only a small part of the Andalusian production and although the agricultural exports are only 15% of all exports, these products contain so much water that the virtual water content of an average million euros of exports is substantially larger than the virtual water content of an average million euros of imports. This finding seems to be in sharp contrast to the HO theory of trade. At the same time, however, it should be mentioned that the Andalusian climate is such that it has a comparative advantage in producing several agricultural products (such as citrus fruits) that require a large amount of sunshine and high temperatures. These "sun intensive" products, however, constitute only a relatively small part of the Andalusian production and exports. No matter whether the results contradict the HO theory or not, the fact remains that one of the most arid regions in Europe is a net exporter of virtual water.

Our central conclusion is that it is necessary to pay attention to cases like water consumption in Andalusia, where a relatively small part of the regional production structure depends heavily on a very limited resource. If policy makers aim at changing this situation in order to arrive at a more sustainable economy that uses the scarce resource less intensively, there seem to be several options. The first is the one that is usually brought to the fore, i.e. technological change. By investing in R&D, new techniques might be developed (e.g. irrigation systems) that reduce the direct water coefficients and additional investments would enable their implementation. The second option is the one that is typically not even taken into consideration. That is, restructuring the production structure, for example by reducing exports that require large amounts of water and stimulating exports of products that are less water intensive. The findings in this paper have shown that the benefits may be substantial while the negative effects are modest. The third option is to introduce water pricing (or increase the current price of water). On the one hand, this will save water because producers are stimulated to use water more efficiently, e.g. by reducing the spoiling of water. On the other hand, this will increase the prices of the products and, in particular, the prices of the water intensive products will be raised the most. In its turn, this will reduce the demand for these products and thus induce a saving of water. The receipts from water pricing may be used by the government to subsidize certain sectors or to offset the price increases for some groups (e.g. domestic consumers). The results in this paper indicate the potential size of the positive effects of water pricing (in terms of water saving) in relation to the negative effects (in terms of a loss in GRP, employment and the trade balance).

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[1] In a similar fashion, international flows of pollutants (such as CO_2, SO_2, and NO_x emissions) and natural resources have been extensively investigated. The input-output framework appears to be a very useful framework, because it takes the interdependent nature of production into full account (see, for example, Antweiler, 1996; Kainuma *et al.*, 2000; Munksgaard and Pedersen, 2001; Machado *et al.*, 2001; Atkinson and Hamilton, 2002; Murudian *et al.*, 2002; Sanchez-Chóliz and Duarte, 2004).

[2] See also the website of the UNESCO-IHE Institute for Water Education (http://www.waterfootprint.org).

[3] The final demands per category are given in the first four columns of Table A1 in the Appendix. Adding the column sums gives the total final demands.

[4] Vectors are columns by definition and a row vector is obtained by transposition, indicated by a prime. A circumflex (or "hat") is used to indicate a diagonal matrix.

[5] The role of water pricing has been extensively discussed in the literature, albeit not in an input-output framework. Recent contributions include Albiac *et al.* (2003); Arbués *et al.* (2004); Brookshire *et al.* (2004); Gómez-Limón and Riesgo (2004); Mejías *et al.* (2004); Embid-Irujo (2005); Garrido (2005); *International Journal of Water Resources Development* (2005); Marques *et al.* (2005); and Reynaud *et al.* (2005).

[6] As far as water is concerned, the last column in Table 2 shows that Andalusia might have been expected to specialize in the production of goods by sectors such as machinery (sector 12), transportation materials (13), footwear and leather products (16), or miscellaneous manufacturing (19). To examine whether Andalusia has a comparative advantage in any of these products, however, would require sectoral data for the use of labor and capital (which are not available).

Table 1. Water resources

	Basin surface (in Km^2)			Resources (in billion liters per year)	
Basin	Total	In Andalusia	Percentage	Surface	Sub terranean
Guadalquivir	57,104	51,477	59	2,255	437
Guadalete/Barbate	6,365	6,365	7	358	85
South	17,820	17,820	20	414	630
Guadiana I	53,067	3,248	4	1	6
Guadiana II	6,871	6,871	8	275	60
Segura	18,870	1,780	2	1	5
Total	160,097	87,561	100	3,304	1,223

Source: Consejería de Medio Ambiente (2004).

Table 2. Aspects of water use at the sectoral level

j	Sector	Water use w_j	Output x_j	Direct Coefficients $y_j = w_j / x_j$	Virtual water multipliers $\Sigma_i y_i l_{ij}$
1	Cereal and legumes	883	482	1,833	1,927
2	Vegetables and fruits	906	1,326	683	693
3	Citrus fruits	321	103	3,129	3,136
4	Industrial plants	183	383	478	505
5	Olive groves	465	836	556	560
6	Other agricultural products	279	1,907	146	258
	Agriculture total	*3,037*	*5,037*	-	-
	average	-	-	*603*	*682*
7	Extractive industry	16	4,705	3	6
8	Water	0	151	0	4
9	Metallurgy	25	1,683	15	19
10	Construction materials	6	1,256	5	9
11	Chemicals and plastics	41	1,727	24	31
12	Machinery	1	1,080	1	4
13	Transportation materials	3	1,542	2	5
14	Food processing	30	6,350	5	190
15	Textiles and apparel	5	1,132	4	41
16	Footwear and leather products	0	99	3	7
17	Wood products	3	823	4	9
18	Paper, printing and publishing	24	629	38	57
19	Miscellaneous manufacturing	1	499	2	5
	Manufacturing total	*155*	*21,676*	-	-
	average	-	-	*7*	*74*
20	Construction	17	7,308	2	7
21	Trade	17	6,107	3	6
22	Hotel and catering trade	71	4,073	17	80
23	Transportation, communications	12	3,748	3	6
24	Sales related services	33	9,188	4	8
25	Non-sales related services	23	5,816	4	8
	Services total	*173*	*36,240*	-	-
	average	-	-	*5*	*15*
	Total	**3,365**	**62,952**	**-**	**-**
	Average	**-**	**-**	**53**	**74**

Table 3. The input-output table

Z	**F**	**x**
$\mathbf{v}'$		
M		
$\mathbf{x}'$		

Table 4. Aggregated results for the final demands and the virtual water contents

	Final demand categories				
	Andalusia	Exports to the Rest of Spain	Exports to the Rest of the EU	Exports to the Rest of the World	Total
	Final demands (as % of total final demands)				
Agriculture	2.7	2.1	0.9	0.1	5.8
Manufacturing	11.2	15.7	3.4	3.1	33.4
Services	59.0	1.8	0.0	0.0	60.8
Total	72.9	19.6	4.3	3.2	100.0
	Virtual water content (as % of total water consumption)				
Agriculture	23.5	19.0	10.0	1.2	53.7
Manufacturing	11.7	16.2	3.5	2.3	33.7
Services	12.5	0.1	0.0	0.0	12.6
Total	47.7	35.3	13.5	3.5	100.0

Table 5. The effects of the nullification of "foreign" exports

	Exports[1]	Water Use[2]	Value added[2]	Labor Costs[2]	Trade Balance[3]
Cereal and legumes	0.10	2.51	0.10	0.14	34.7
Vegetables and fruits	0.73	6.86	0.79	2.17	290.0
Citrus fruits	0.02	1.17	0.03	0.19	11.3
Industrial plants	0.03	0.19	0.02	0.09	8.2
Olive groves	0.00	0.01	0.00	0.01	0.6
Other agricultural products	0.12	0.42	0.12	0.18	46.0
Total Agriculture	*1.00*	*11.17*	*1.07*	*2.80*	*383.8*
Food processing	1.94	4.99	1.84	2.67	662.2
Total Manufacturing	*6.52*	*5.83*	*5.41*	*9.56*	*1,942.6*
Total Services	*0.05*	*0.00*	*0.06*	*0.02*	*23.4*
Total	7.57	17.00	6.54	12.38	2,349.7

1) Exports as percentage of the total final demands. 2) Reduction in water use (value added, labour costs) as percentage of the actual water use (resp. value added, labour costs). 3) Deterioration of the Andalusian trade balance in million euros.

Table 6. Virtual water content of one million euros of imports and exports

	Import distribution (as percentage)	Virtual water content (in million liters)	Export distribution (as percentage)	Virtual water content (in million liters)
Trade with the rest of Spain				
Agriculture	5.3	39.3	10.8	71.6
Manufacturing	76.0	31.7	80.1	60.9
(of which food processing)	(10.2)	(19.4)	(27.8)	(52.8)
Services	18.8	1.1	9.0	0.5
Total	100.0	72.2	100.0	133.1
Trade with the rest of the EU				
Agriculture	13.7	80.7	20.3	168.8
Manufacturing	86.0	21.6	78.9	58.8
(of which food processing)	(3.6)	(6.8)	(26.9)	(51.1)
Services	0.3	0.0	0.8	0.1
Total	100.0	102.3	100.0	227.6
Trade with the rest of the world				
Agriculture	7.4	52.3	3.6	26.6
Manufacturing	92.4	12.6	95.8	53.6
(of which food processing)	(2.6)	(4.9)	(23.7)	(44.9)
Services	0.1	0.0	0.7	0.0
Total	100.0	64.9	100.0	80.3
All trade				
Agriculture	6.4	45.4	11.5	82.0
Manufacturing	80.2	26.9	81.8	59.7
(of which food processing)	(8.1)	(15.4)	(27.2)	(51.6)
Services	13.4	0.8	6.7	0.4
Total	100.0	73.2	100.0	142.1

Table A1. Detailed results for the final demands and the virtual water contents

j		f_j^{AND} (1)	f_j^{RoS} (2)	f_j^{RoEU} (3)	f_j^{RoW} (4)	$\Sigma_i y_i l_{ij} f_j^{AND}$ (5)	$\Sigma_i y_i l_{ij} f_j^{RoS}$ (6)	$\Sigma_i y_i l_{ij} f_j^{RoEU}$ (7)	$\Sigma_i y_i l_{ij} f_j^{RoW}$ (8)
1	Cereal and legumes	34.6	74.1	40.8	3.4	66.3	142.0	78.2	6.5
2	Vegetables and fruits	573.5	311.4	296.0	37.1	397.4	215.8	205.1	25.7
3	Citrus fruits	44.8	36.6	11.3	.3	140.5	114.8	35.4	4.0
4	Industrial plants	1.6	46.2	11.9	0.6	0.8	23.3	6.0	0.3
5	Olive groves	136.1	49.8	0.8	0	76.2	27.9	0.5	0
6	Other agricultural products	420.5	449.5	44.7	10.0	108.4	115.9	11.5	2.6
7	Extractive industry	1,052.8	1,187.1	126.3	169.6	6.5	7.4	0.8	1.1
8	Water	42.4	0	0	0	0.2	0	0	0
9	Metallurgy	300.1	334.3	319.1	235.1	5.6	6.2	5.9	4.4
10	Construction materials	50.0	301.0	20.1	20.1	0.5	2.8	0.2	0.2
11	Chemicals and plastics	141.9	627.0	151.2	121.2	4.5	19.7	4.8	3.8
12	Machinery	301.2	524.3	32.5	15.2	1.2	2.1	0.1	0.1
13	Transportation materials	313.0	360.9	259.2	452.4	1.6	1.9	1.3	2.3
14	Food processing	1,765.6	2,481.8	536.6	346.7	335.4	471.4	101.9	65.9
15	Textiles and apparel	352.4	613.5	38.1	17.8	14.5	25.3	1.6	0.7
16	Footwear and leather products	26.1	51.8	9.2	6.0	0.2	0.3	0.1	0.0
17	Wood products	318.3	270.7	57.7	7.5	2.9	2.5	0.5	0.1
18	Paper, printing and publishing	359.3	52.4	0.9	0.6	20.4	3.0	0.1	0.0
19	Miscellaneous manufacturing	94.8	349.7	23.2	11.3	0.5	1.8	0.1	0.1
20	Construction	6,856.2	0	0	0	50.9	0	0	0
21	Trade	4,378.1	638.3	10.5	7.0	24.7	3.6	0.1	0.0
22	Hotel and catering trade	3,142.2	0	0	0	252.3	0	0	0
23	Transportation, communications	1,443.4	146.3	5.3	2.8	8.5	0.9	0.0	0.0
24	Sales related services	5,302.4	22.8	0	0	40.6	0.2	0	0
25	Non-sales related services	5,809.0	0	0	0	43.9	0	0	0
	Total	33,260.3	8,929.6	1,995.3	1,465.6	1,604.4	1,188.5	454.2	117.7

Note: final demands in columns (1)-(4) in million euros; virtual water contents in columns (5)-(8) in billion liters.